Elastic $p^{\uparrow}C \rightarrow pC$ Scattering at Very Low Momentum Transfer t and RHIC Polarimetry

A. Bravar, I. Alekseev, L. Ahrens, M. Bai, G. Bunce, S. Dhawan,
H. Huang, V. Hughes, G. Igo, O. Jinnouchi, K. Kurita, Z. Li,
W.W. MacKay, S. Rescia, T. Roser, N. Saito, H. Spinka, D. Svirida,
D. Underwood, C. Whitten, J. Wood

CIPANP 2003
New York, May 19 – 24

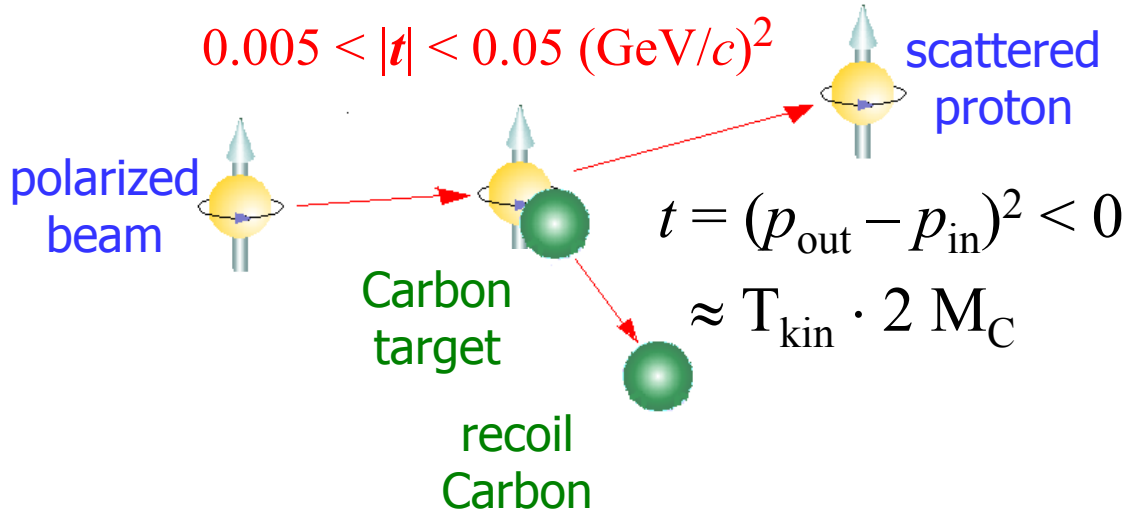
Alessandro Bravar

BROOKHAVEN
NATIONAL LABORATORY

Elastic $pC \rightarrow pC$ scattering at low t

$$A_N = -\frac{1}{P_B} \cdot \frac{N_{left} - N_{right}}{N_{left} + N_{right}}$$

recoil



1. A_N from interference of spin non-flip and spin flip amplitudes
   $\Rightarrow$ spin dependence of interaction
   $\Rightarrow$ hadronic spin flip (spin-coupling of Pomeron)

2. RHIC Polarimetry
   - almost "calculable"
   - sizeable $A_N \sim 1$ % (requires large statistics $> 10^7$)
   - large cross section
   - weak beam momentum dependence (p > 20 GeV/c)

A_N: from where does it come?

$$\sigma = |A_{hadronic} + A_{Coulomb}|^2 \qquad (|\mathbb{P} + \gamma|^2)$$

around $t \sim -10^{-3}$ (GeV/c)^2 $A_{hadronic} \approx A_{Coulomb} \Rightarrow$ INTERFERENCE

CNI = Coulomb – Nuclear Interference

unpolarized $\Rightarrow$ clearly visible in the cross section $d\sigma/dt$ (charge)

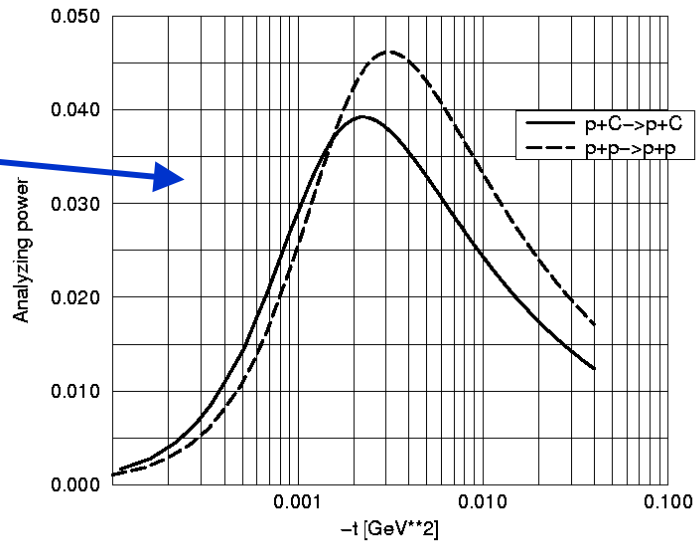
polarized $\Rightarrow$ left – right asymmetry A_N (magnetic moment)

$$A_N = C_1 \Phi_{em}^{*flip} \Phi_{had}^{non-flip} + C_2 \Phi_{em}^{non-flip} \Phi_{had}^{flip}$$

$\propto (\mu - 1)_p$ $\qquad$ $\propto \sqrt{\sigma^{pp}_{had}}$

QED $\Rightarrow$ "calculable", expect $A_N \neq 0$ up to 4.5%

$$A_N = \sqrt{\frac{8\pi Z\alpha}{m_p^2 \sigma_{tot}^{pA}}} \frac{y^{3/2}}{1+y^2}(\mu - 1); \qquad y = \frac{\sigma_{tot}^{pA}\, t}{8\pi Z\alpha}$$



QCD $\Rightarrow$ "unpredictable", need direct measurement

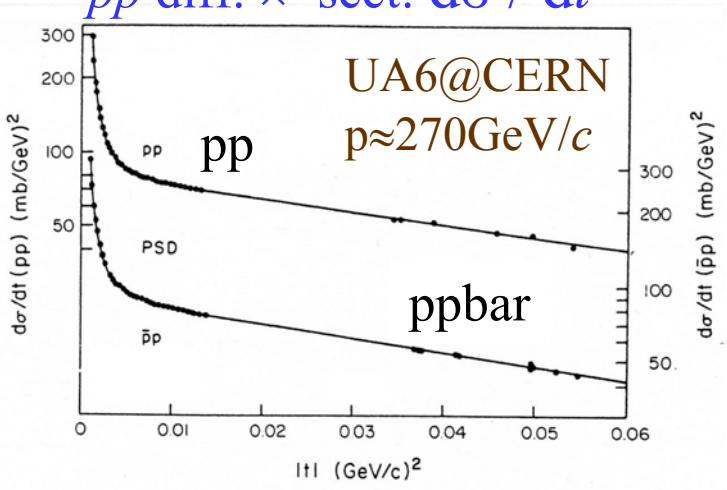
$$g_5(s,t) = \tau(s) \cdot \sqrt{|t|}/m_p \cdot g_0(s,t) \qquad g_0(P, f, \omega)$$

$$r_5^{pC}(s,t) = \tau(s)\left(i + \rho_{pC}(s,t)\right) = m_p / \sqrt{|t|} \cdot F_s^{had} / \Im F_0^{had}$$

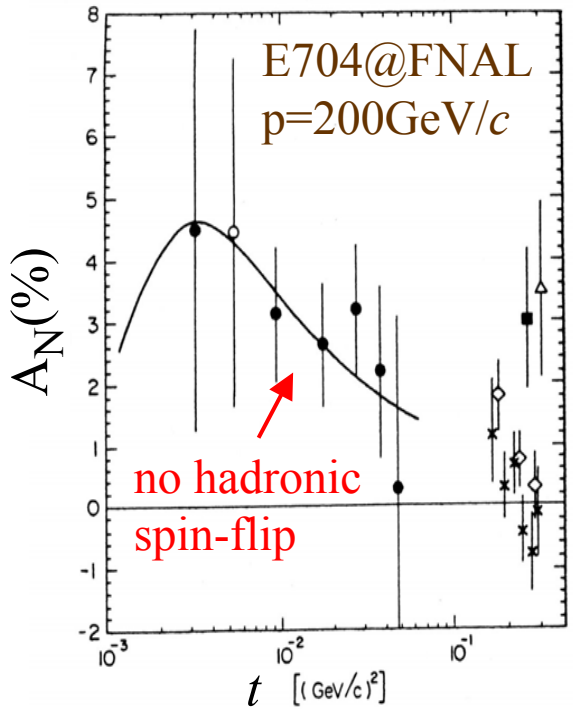
B. Kopeliovich & L.Trueman

Elastic *pp* & *pC*: dσ / d*t* and A_N

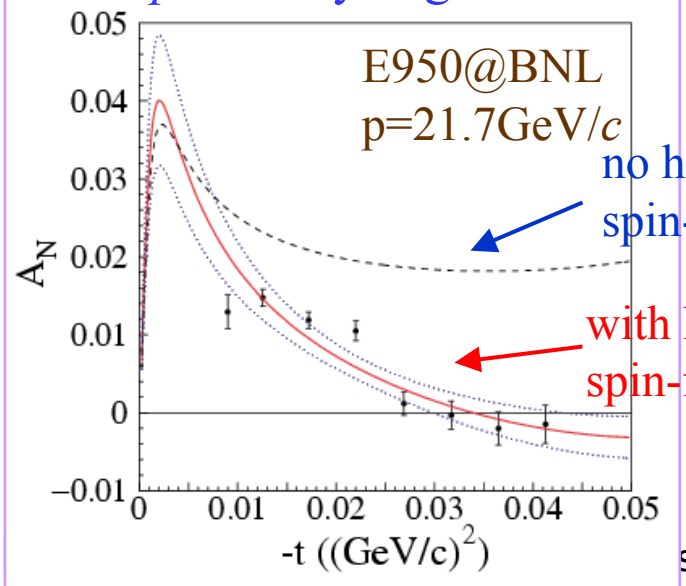
pp diff. ×–sect: dσ / d*t*



pp Analyzing Power A_N



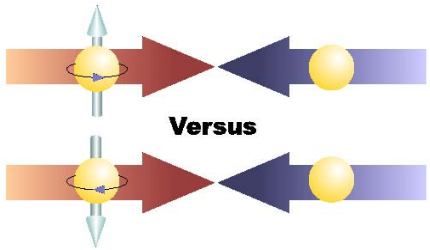
pC Analyzing Power



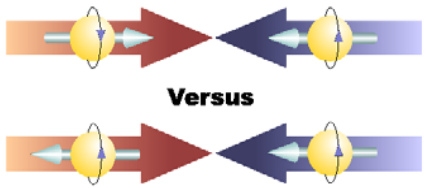
$$r_5^{pC} = 0.088 \pm 0.058 - i\,0.161 \pm 0.226 \propto F_s^{had} / Im\, F_0^{had}$$

Polarimetry : Impact on Spin Physics

Single Spin Asymmetries



Double Spin Asymmetries



Physics Asymmetries

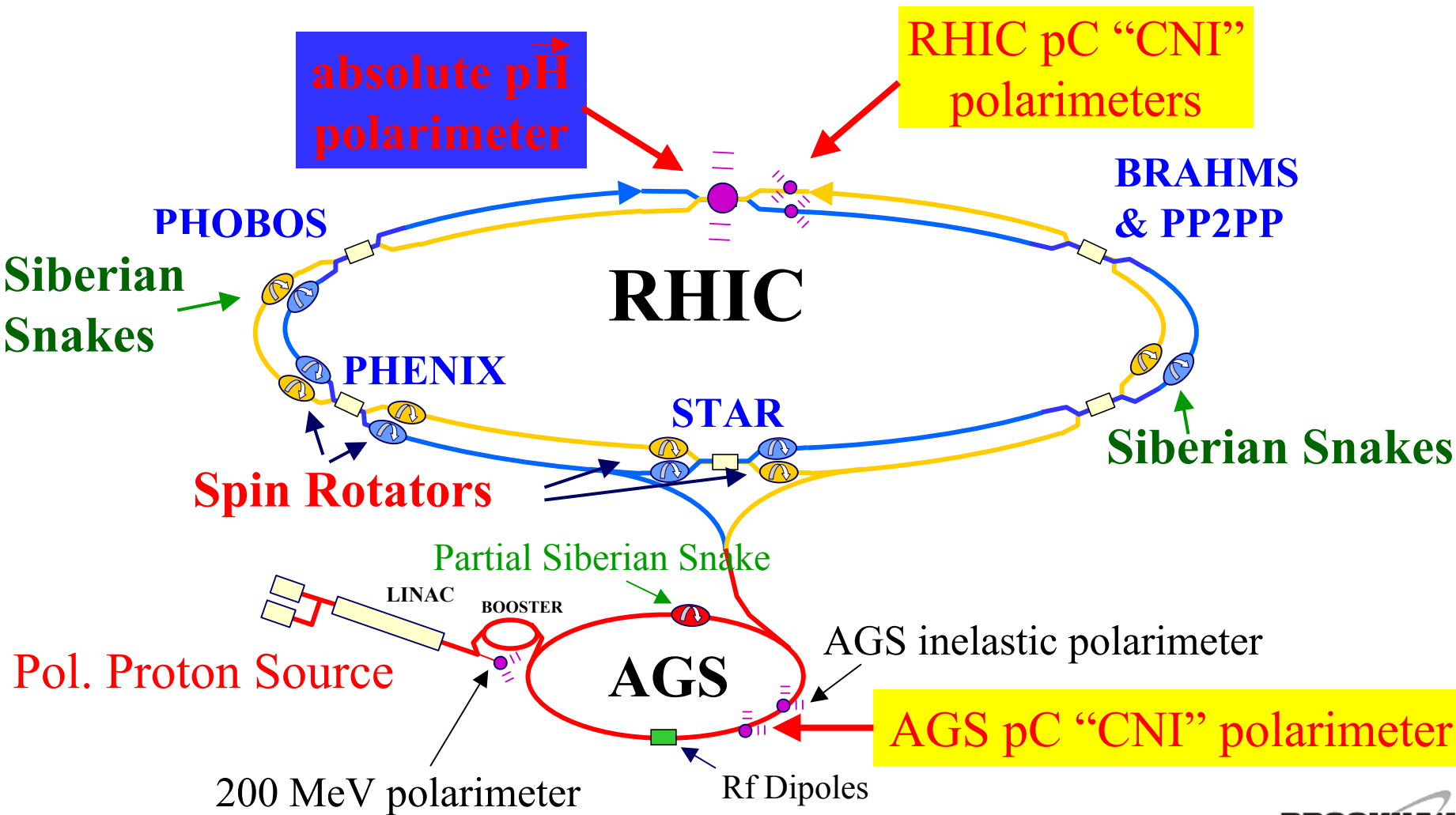
$$A_N = \frac{1}{P_B}\left(\frac{N_\uparrow - N_\downarrow}{N_\uparrow + N_\downarrow}\right)$$

$$A_{LL} = \frac{1}{P_B^2}\left(\frac{N_{\uparrow\uparrow} - N_{\uparrow\downarrow}}{N_{\uparrow\uparrow} + N_{\uparrow\downarrow}}\right)$$

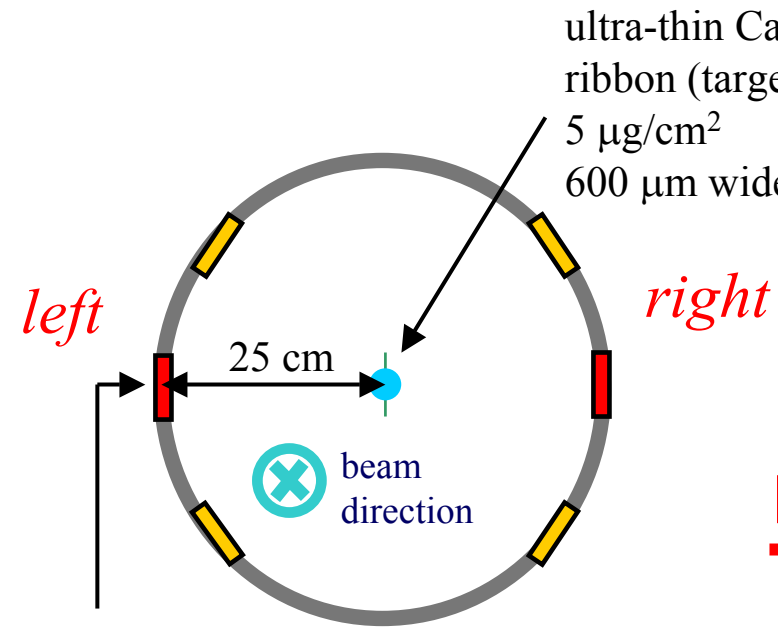
- In any Spin asymmetry measurement, the raw asymmetries have to be normalized by the beam(s) polarization to obtain the Physics Spin Observables (A_N, A_{LL} , etc.)
- Elastic *p*C Scattering in CNI (Coulomb Nuclear Interference) region adopted as polarimeter for its fast and reliable measurement performance
- Need of absoulte calibration via Elastic *pp* Scattering in CNI region using a polarized gas jet target (planned for run `04)

RHIC: the "Polarized" Collider

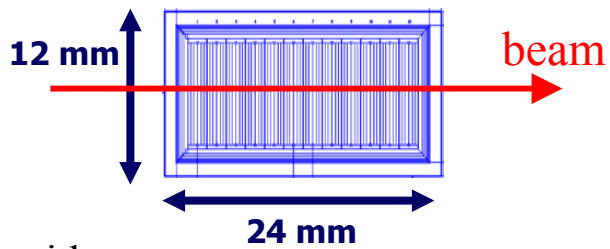
70% Polarization $L_{max} = 2 \times 10^{32}\ s^{-1}cm^{-2}$ $50 < \sqrt{s} < 500$ GeV



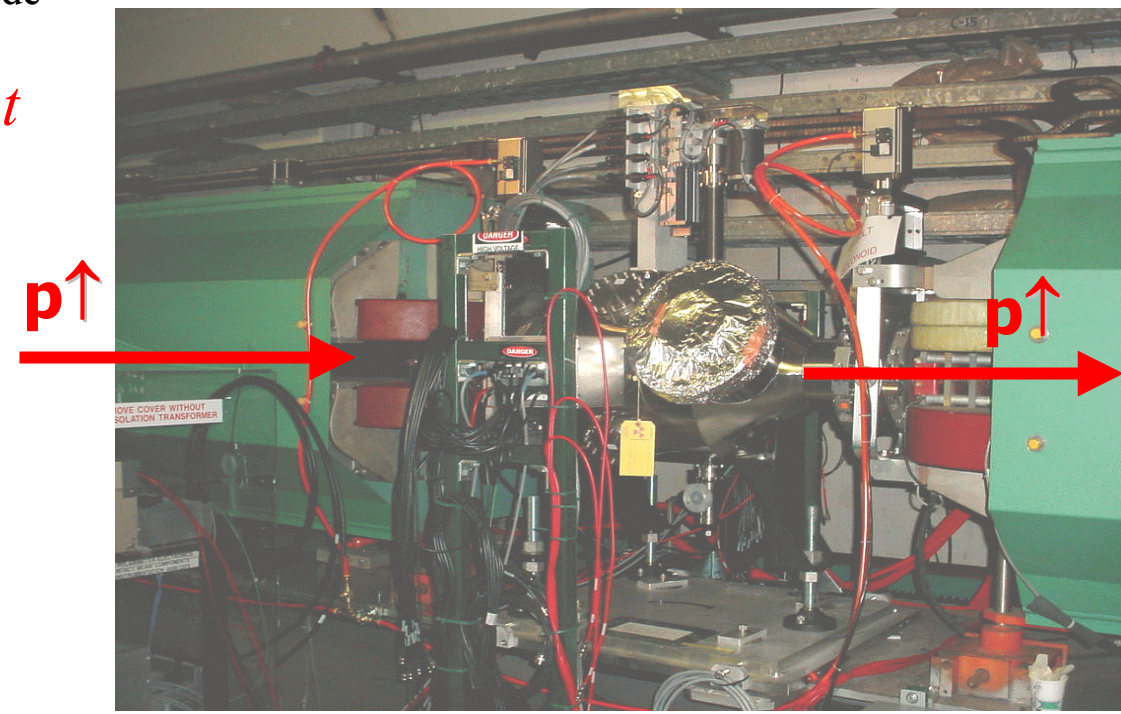
Elastic $p\uparrow$C Scattering Setup in the AGS Ring



Si strip detectors
12 vertical strips



read-out with
waveform digitizers



similar setups in RHIC for each beam

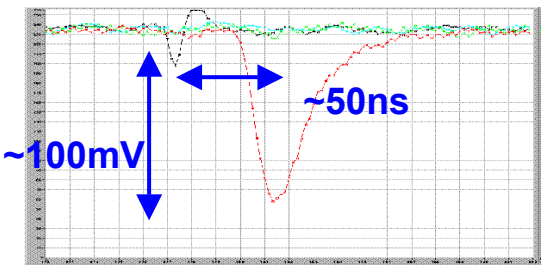
Event Selection

- recoil carbons detected with Si detectors
- "identified" via ToF vs Enery correlation

  position vs energy correlation spoiled by multiple scattering in target

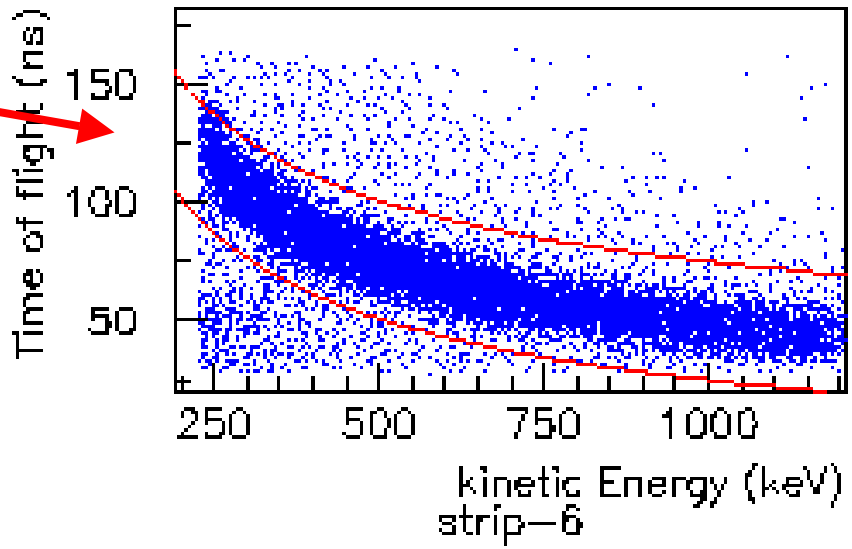
- very high event rate

  events acquired with deadtime free wave-form digitizers



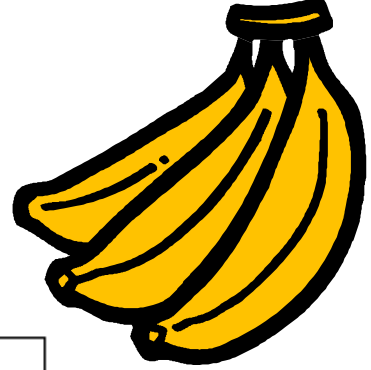
$$T_{kin} = \tfrac{1}{2} M_C \, (dist / ToF)^2$$

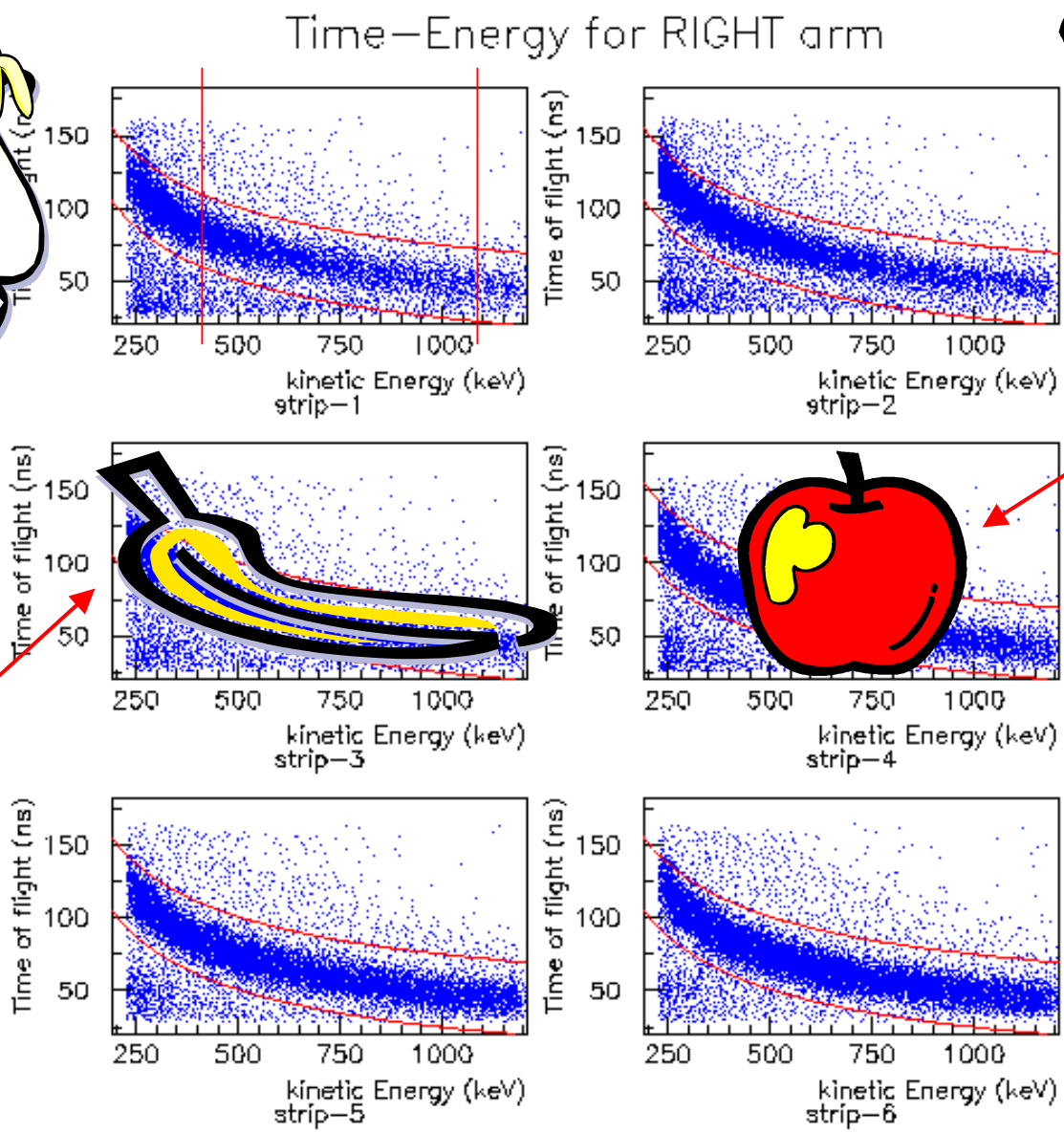
non-realativistic kinematics



- carbon "events" found / selected in ToF vs. T_{kin} correlation band
- background events below 1% within the "banana" cut

Time of Flight vs. Energy i.e.

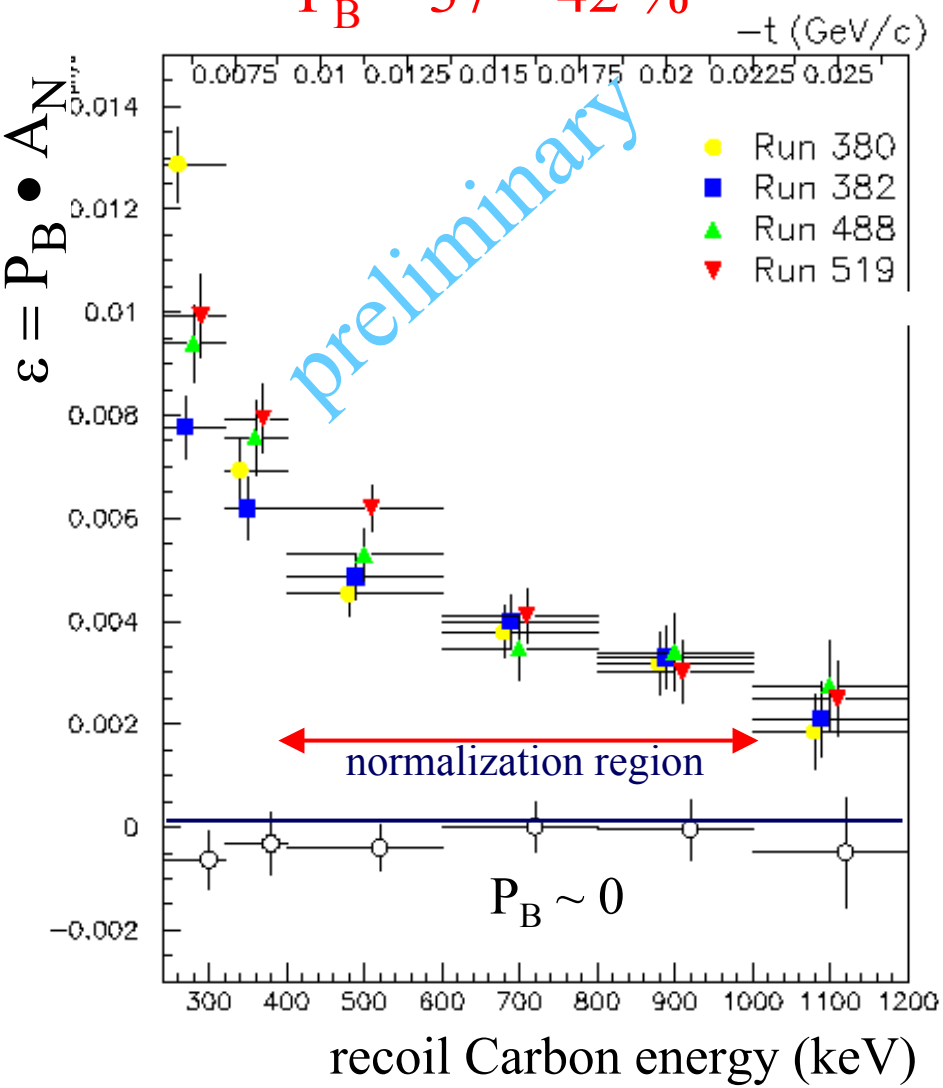




does not pass the cuts

event selection

$p\uparrow$C *raw* asymmetry at 24.7 GeV/*c*



$$P_{beam} = \frac{1}{\langle A_N \rangle} \cdot \varepsilon_N$$

$$\langle A_N \rangle = \frac{\sum N(t_i) A_N^{th}(t_i)}{\sum N(t_i)}$$

calculated over several *t* bins

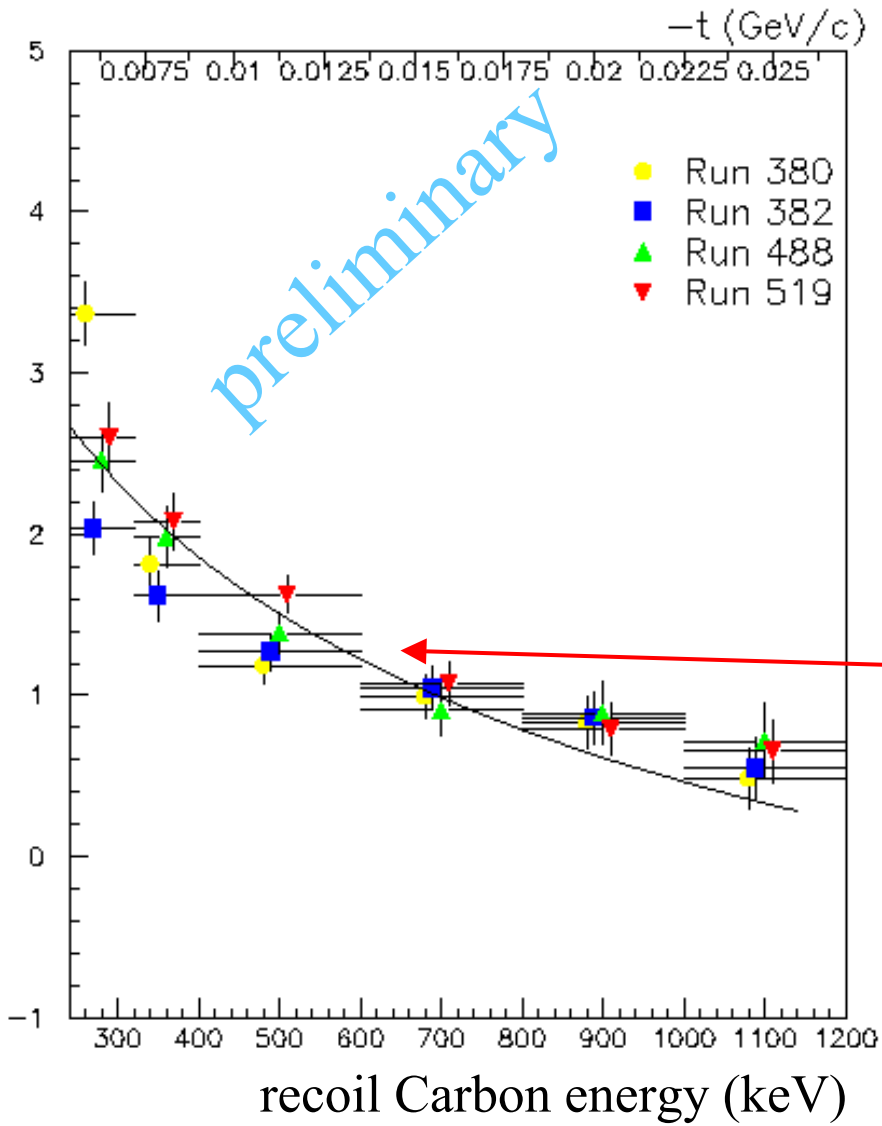
A_N^{th} from a fit to E950 data at similar energy and ***t*** range

L. Trueman hep-ph/0305085

$\langle A_N \rangle \approx 1.12$

$0.009 < |t| < 0.022\ (\mathrm{GeV}/c)^2$

A_N: $p\uparrow C \rightarrow pC$ at 24.7 GeV/c

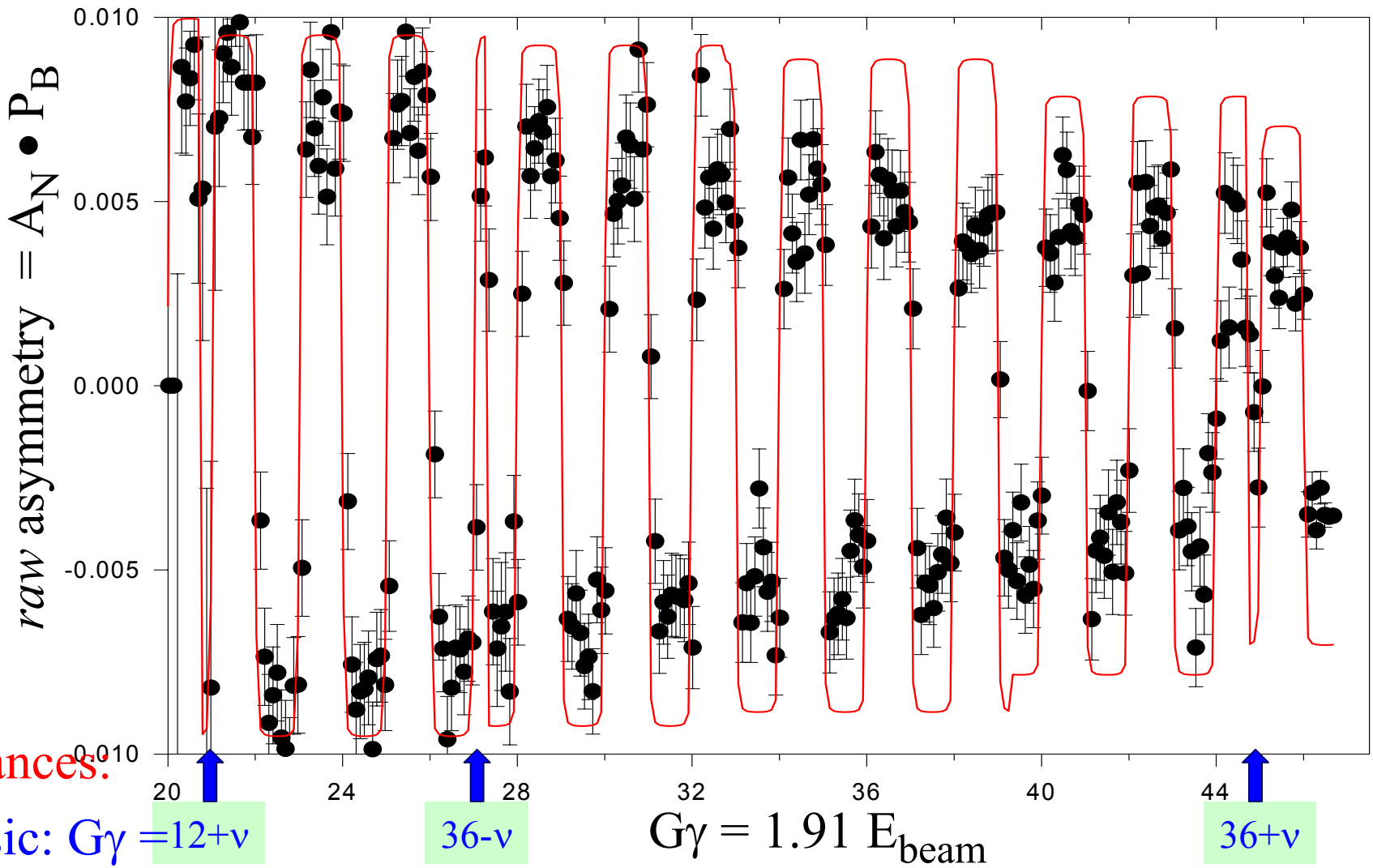


- only statistical errors shown
- normalization error (i.e. P_B) ~ 25% (relative)
- systematic error (background, pileup, etc.) < 20% (relative)

fit to E950 data
L. Trueman hep-ph/0305085

similar behavior E950 ⇒ substantial hadronic spin-flip confirmed
(no time yet to fit these data)

AGS Polarization during acceleration (ramp)

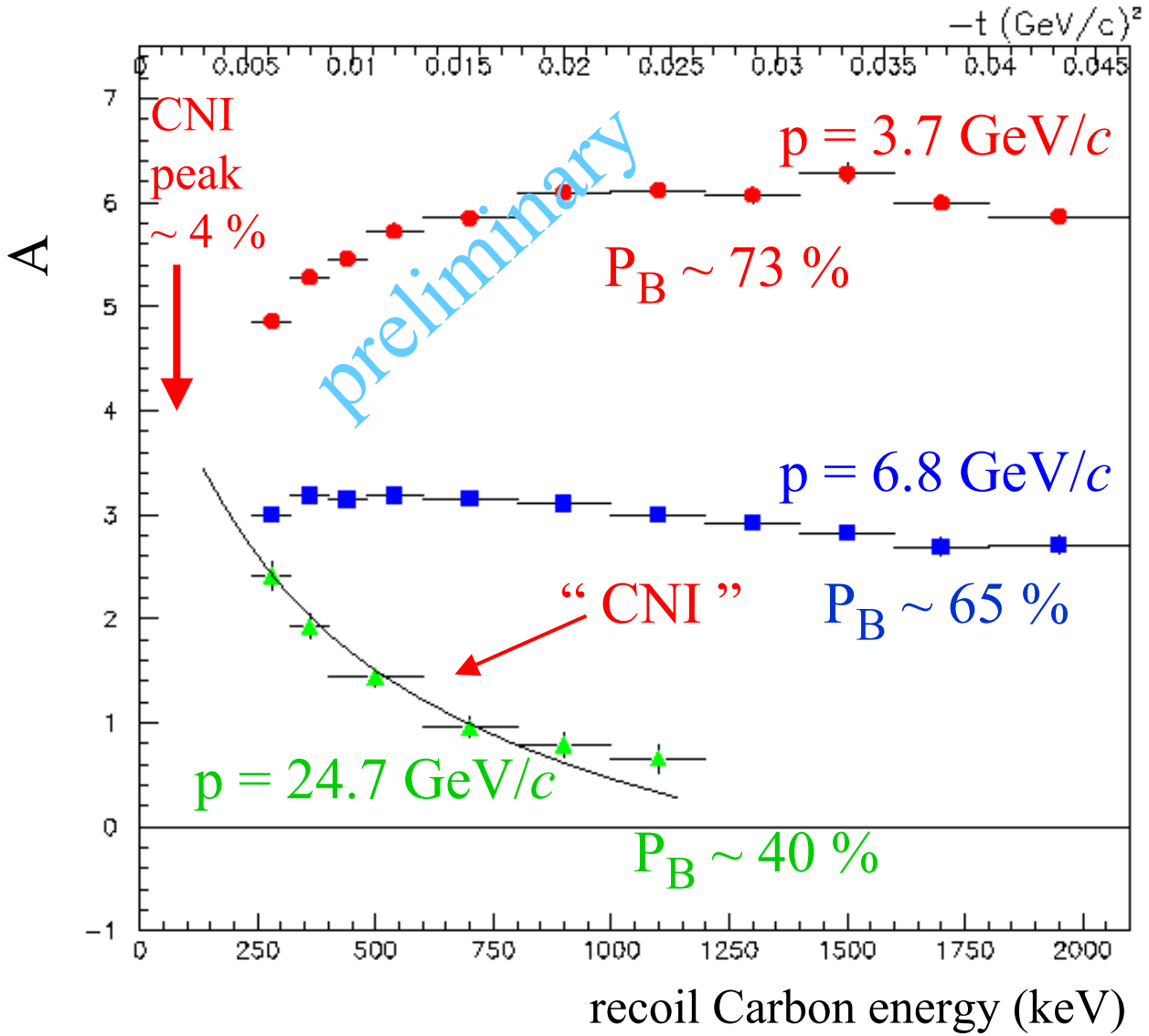


resonances:

intrinsic: Gγ = 12+ν, 36-ν

imperfection: Gγ = n

A_N: $p\uparrow C \rightarrow pC$ at 3.7 & 6.8 GeV/c

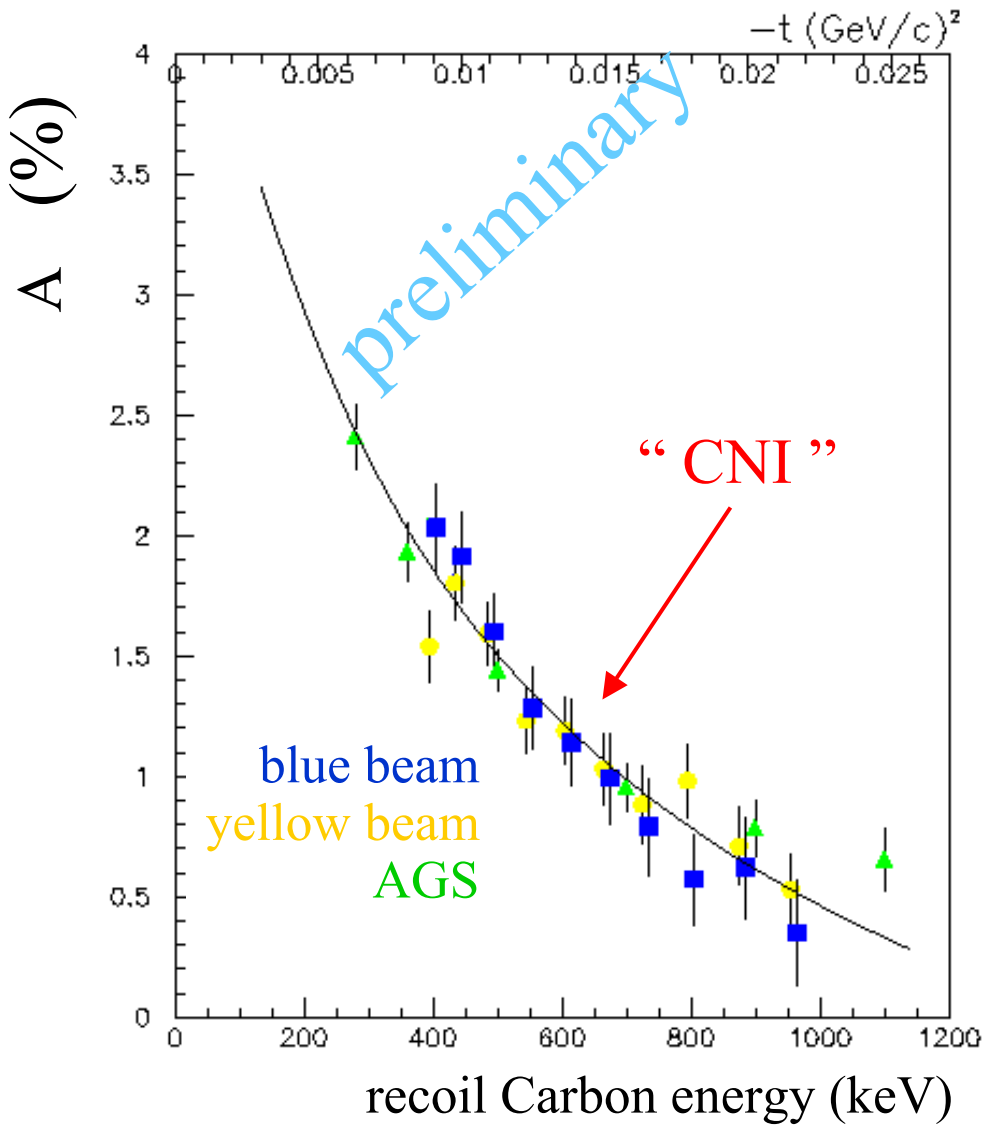


only statistical errors are shown

normalization errors:
- ~ 10 % (at 3.7)
- ~ 15 % (at 6.8)
- ~ 25 % (at 24.7)

systematic error:
- < 20 %

A_N: $p\uparrow C \rightarrow pC$ at RHIC energy (100 GeV/c)



for normalization assume
A_N (24 GeV/c) = A_N (100 GeV/c)
i.e. no energy dependence
[$0.009 < |t| < 0.022$ (GeV/c)^2]

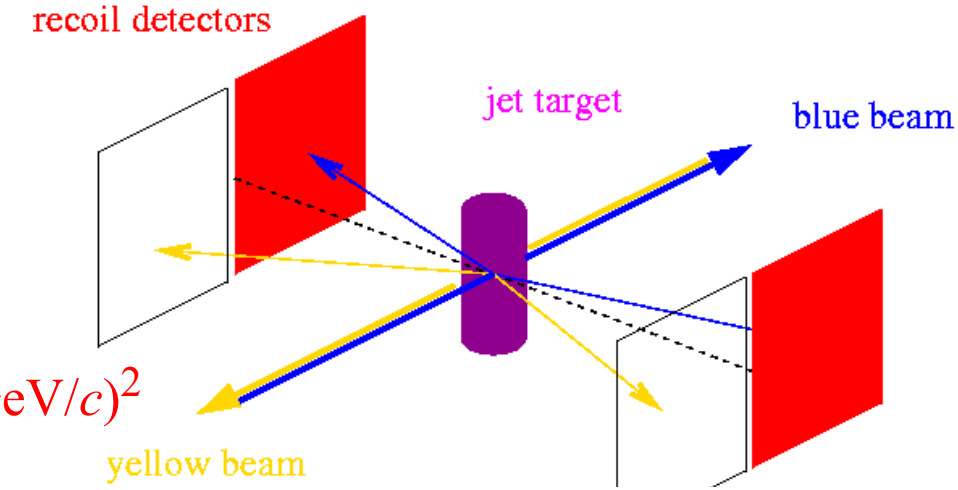
very similar shape of the t dependence at 24 and 100 GeV/c

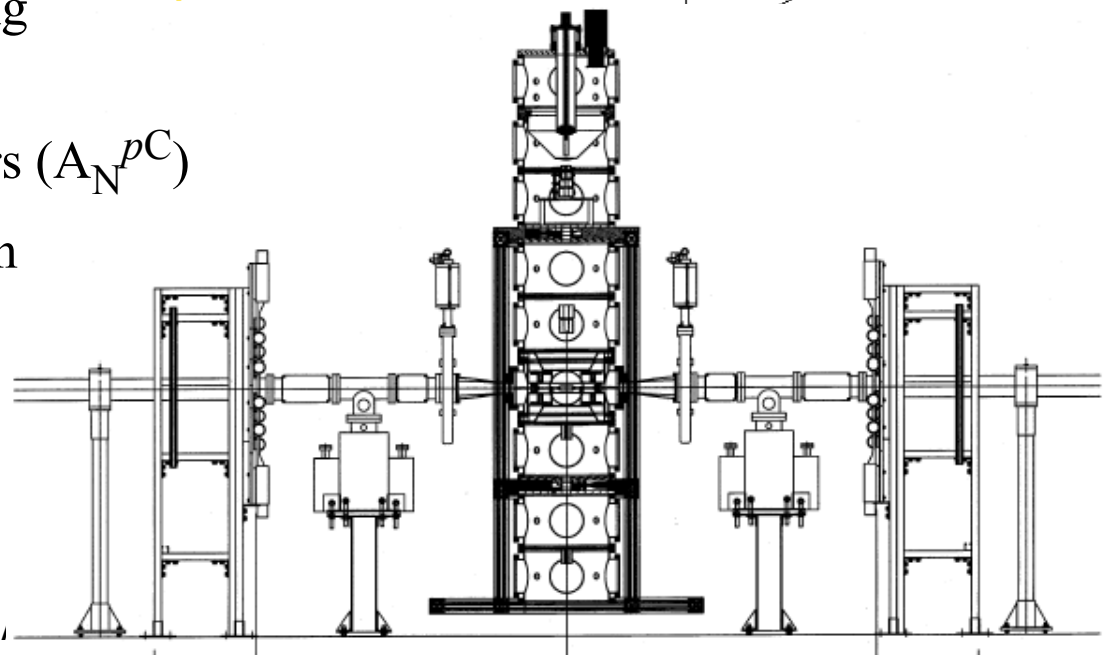
$\Rightarrow$ suggestive of very small energy dependence for A_N between 24 and 100 GeV/c

systematic error for RHIC data < 15%

Next: $p\uparrow p$, $pp\uparrow$ and $p\uparrow p\uparrow$ with a Polarized Gas Jet Target

- Polarized Hydrogen Gas Jet Target
  thickness of 5×10^{11} p/cm^2
  polarization > 90%
- Silicon recoil detectors
- Rate: 125 Hz for $0.001 < |t| < 0.02$ (GeV/c)^2
- Measure A_N^{pp} in pp elastic scattering in the CNI region to a 3% accuracy
- Transfer A_N^{pp} to the pC polarimeters (A_N^{pC})
- Expected accuracy on P_B of 6% with "calibrated" pC CNI polarimeters
- Install for the '04 run
- Initially measure P_B to 10%





Summary

- measured A_N^{pC} for elastic $pC \rightarrow pC$ scattering
  - $0.005 < |t| < 0.05$ (GeV/c)^2 & $3.5 < p_{beam} < 100$ GeV/c
- $p_{beam} < 10$ GeV/c
  - almost no t dependence
  - departure from "CNI" behavior
- $p_{beam} > 20$ GeV/c
  - same t dependence
  - suggestive no (or small) energy dependence
  - (very) consistent with hadronic spin-flip @ 15% level

- RHIC POLARIMETRY
  - works reliably, fast measurements of P_B
  - need "absolute" calibration ⇒ polarized gas jet target
  - 2004 $P_B \sim 10$ %; 2005 $P_B \sim 6$ (5) %